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Potato Wilt and Its Control

By

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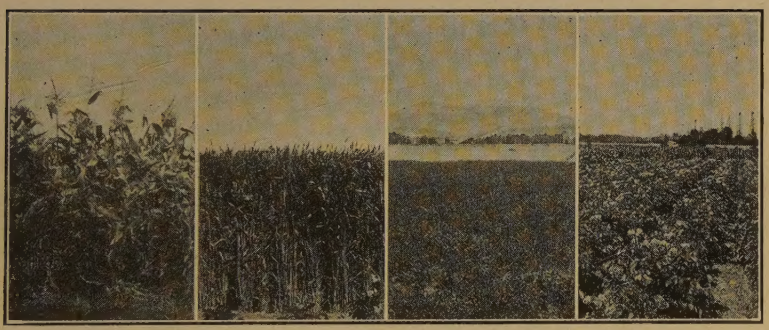


A four-year rotation is desirable for potatoes. Proper rotation of crops is one necessary practice for avoiding the holding over of potato diseases in the soil. For potato wilt control at least a four-year rotation should be used. The one shown here makes use of corn, grain, clover, and potatoes. The best basic crop rotation for Western Oregon is grain, clover seed, clover hay, and a cultivated crop. A variety of materials including potatoes, corn, kale, etc., may be used for the cultivated crop. This may, of course, be varied if desired better to suit local needs.

CORVALLIS, OREGON

HE wilt disease of potatoes is responsible for appreciable losses each year in Oregon. Loss occurs both in diminished yields and in lowered quality of the potatoes for seed purposes. Reductions in yield varying from 15 percent to 70 percent in individual plants may result from this disease.

All of the leading commercial varieties are susceptible to this disease, which occurs in every important potato area of the state.

Wilt is carried over from one crop to another in seed potatoes and in the soil. Seed selection and crop rotation are the means by which the perpetuation of this disease can be avoided.

Seed selection for wilt control is effectively accomplished only in a seed-plot. This makes possible the roguing of diseased plants when they can be most accurately recognized. Because the disease often spreads to the adjoining plant in the row without producing distinct symptoms, effective control of the disease cannot be secured by the roguing of only the visibly wilted plants. Consequently, use must be made of the three-plant method of roguing; that is, the noticeably wilt-diseased plant and the next adjoining healthy appearing plant on either side in the same row should be removed at the same time. In every locality where home-grown seed can be maintained in good productive condition from year to year, the use of a seed-plot should become a part of the general practice of every farm.

For potato wilt control at least a four-year rotation should be used. The more general use of well planned crop rotation systems would do much to lessen the damage from potato diseases. As a general agricultural practice, crop rotation has everywhere proved a necessity to successful farming.

Potato Wilt and Its Control

By

M. B. McKay

Wilt is one of the half-dozen more serious diseases commonly affecting potatoes in Oregon. From the standpoint of difficulty of control, it probably ranks second among all the diseases affecting potatoes here, only the virus diseases being more difficult to restrain. Wilt has long been known, and at times some confusion has been experienced in the recognition of the symptoms of the disease and in the application of measures intended for its control. Because our knowledge of the disease was very incomplete, the Oregon Agricultural Experiment Station conducted a study of this disease extending over the years 1916 to 1924, the detailed results from which have already been published.* In addition progress has been made in other places toward a more complete understanding of the problem of wilt control.

It is the purpose of the present publication to give the essential details of facts now known concerning potato wilt that will enable growers more accurately to recognize the disease and more effectively to apply control measures of demonstrated value. With the information now available it can be quite successfully controlled though only at the cost of painstaking care intelligently applied.

CAUSE OF POTATO WILT

Potato wilt is caused by the growth of organisms in the tissues of the stem and roots of the plant. This results in a plugging of the water-conducting vessels, the production of poisonous substances, or the destruction of the tissues to such an extent that normal functions cannot be performed. Under such circumstances the leaves lose their color, wilt, and the whole plant finally dies. Several different organisms have been encountered which produce wilting of potatoes. The most important wilt producing organisms are *Verticillium albo-atrum* (R. and B.), *Fusarium oxysporum* (Schlecht.), and *Fusarium eumartii* (Carp.). Only the first two have been found causing wilt of potatoes in Oregon, and of these two *V. albo-atrum* occurs more frequently and causes greater reduction in the yield. Most of the information given here applies particularly to the wilt caused by this organism, though the control measures given are appropriate to the potato wilt diseases as a group.

DESCRIPTION OF POTATO WILT

The two serious potato wilt diseases in the state caused by distinct organisms are so similar in appearance that they may be described together. Attacked plants may wilt rather suddenly and die in a comparatively short time or they may and usually do show the effects slowly and succumb very gradually. Plants produced from infected tubers may be stunted from the beginning and die without attaining average size (Fig. 1). Those contracting

*McKay, M. B. Transmission of some wilt diseases in seed potatoes. Jour. Agr. Research 21:821-848. 1921.

———— Further studies of potato wilt due to Verticillium albo-atrum. Jour. Agr. Research 32:437-470, 1926.

the disease from neighboring plants or from the soil show their first indication of the disease in the yellowing and drooping of the lower older leaves, followed by the gradual yellowing, browning, and wilting usually of the

Fig. 1. Plant at left wilting and dying prematurely from attack of wilt due to Verticillium, grown from a tuber known to be wilt-infected when planted. It produced six tubers weighing 10 ounces, 50 percent of which were infected with Verticillium when dug. The one at the right was grown from a wilt-free tuber. It remained healthy in appearance nearly up to the end of the growing season, and produced a large yield of 22 tubers, weighing 7 pounds and 10 ounces; yet when tested after harvest 45 percent of these tubers showed infection by Verticillium wilt. Without question, infection of this plant resulted from spread of the disease from the adjoining diseased plant in the row.

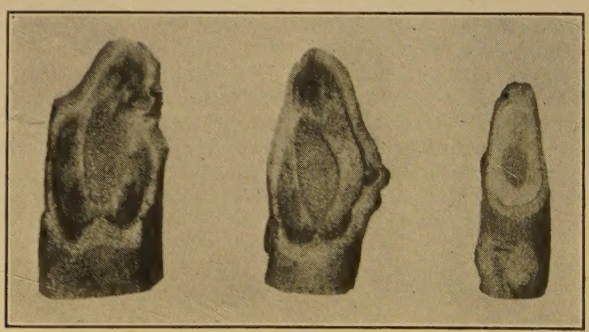


Fig. 2. Oblique sections of potato stalks, at left from Verticillium wilt-diseased plants, showing the browning of the vascular or woody tissues caused by the wilt fungus, and at right from healthy plant. The exteriors of these stalks are normal in appearance.

entire plant (Figs. 8 and 11). The stems of affected plants are invariably discolored in the interior. The vascular or woody tissues of the interior of the stem are yellow to brown in color (Fig. 2), often extending from the base well into the top. The exterior of such stems commonly appears normal. The tubers in wilt-affected hills often, though less regularly, show a brown-

ing of the water vessels (Fig. 3). These discolored tissues show as yellow to brown or black strands, or a ring extending for varying distances into the tuber at the stem end from the point of stolon attachment. The discoloration is confined to the vascular tissues, which when normal appear as a faint

Fig. 3. Discolored vascular tissue at stem end of potato tubers affected with the two wilt-producing organisms which are common in Oregon. Up-to-Date tuber affected with Verticillium at left, Early Rose tuber affected with Fusarium at right. These wilts cannot be separated on the basis of discoloration present nor can discoloration be used reliably to distinguish wilt-infected from wilt-free tubers.

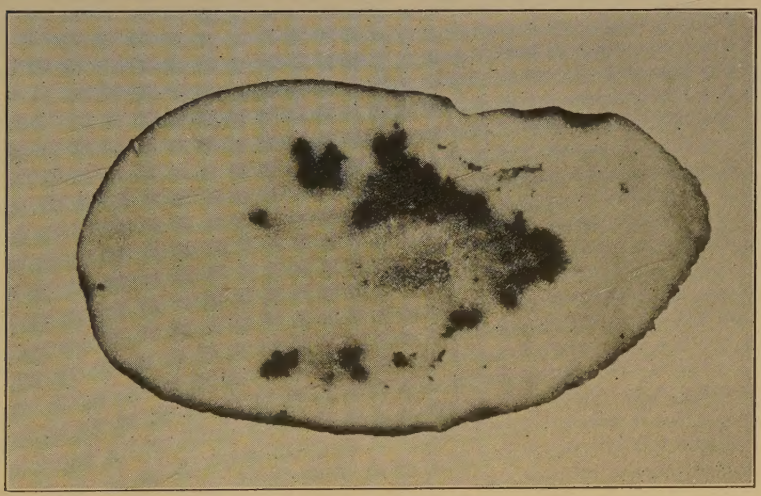


Fig. 4. Tuber affected by Internal Brown Spot. This type of discoloration in potato tubers is sometimes on superficial examination confused with wilt though it is due to a very different condition. It is characterized by the occurrence of irregular brown spots or groups of cells which may occur at any place in the flesh of the tuber and is caused by shortage of moisture at some period during growth, whereas the wilt discoloration is confined to the vascular ring and extends in from the stem end.

layer located about $\frac{1}{4}$ inch beneath the skin. This type of discoloration in the vascular ring is sometimes confused with, but is quite readily distinguished from, the very different trouble called Internal Brown Spot. This latter trouble is characterized by irregular, dry, brown spots or blotches, varying in size up to $\frac{1}{2}$ inch or more in diameter, and occurs in scattered places in

the flesh of the tuber, usually inside of the vascular ring (Fig. 4). The tissues affected by Internal Brown Spot are free from pathogenic bacteria and fungi and represent merely groups of cells which have died apparently from lack of water at some period during the growth of the plants.

Fig. 5. Brown, dead, cankerous areas on stalk and stolons due to Rhizoctonia. This injury is sometimes confused with, but is easily distinguished from wilt discoloration, which occurs in the interior tissues of the stems.

Fig 6. Plant affected with blackleg. This also is occasionally confused with wilt though in anything like typical form it is readily distinguished from it. Blackleg characteristically shows as a black decay of the entire stalk progressing up from the base. The seed piece is invariably rotted.

Unfortunately, discoloration of the vascular tissues of the stems and tubers, indistinguishable from that caused by the presence of a wilt fungus, may be induced at times by trying conditions during growth such as high soil and air temperatures, dry soil, early frost, the presence of unimportant fungi, etc., and cannot, therefore, be relied on as a sure symptom of wilt. Under such circumstances accurate diagnosis of the disease in the field or in the bin is impossible without resorting to cultures to determine the presence of wilt-producing fungi. In general, however, wilt can be quite accurately recognized in the field when any considerable number of diseased plants are present.

Aside from the premature dying of the plants and discoloration of the stems from other causes than wilt, the two diseases most commonly confused with wilt in the field are Rhizoctonia and Blackleg. When these are present in anything like typical form they are as a rule readily differentiated from wilt on the basis of their below-ground features. Rhizoctonia commonly shows as brown, dead, cankerous areas on the surface of the stalks below ground, the interior often appearing normal (Fig. 5). Blackleg is characterized by an inky black decay of the main stalk progressing up from the point where it is attached to the parent tuber, both interior and exterior tissues being involved (Fig. 6). The seed piece is invariably rotten, usually in a pulp.

WILT DISEASES ARE CARRIED IN SEED POTATOES

That potato wilt producing fungi are carried in seed potatoes from one crop to another has long been known, and methods have been recommended for the avoidance of this source of contamination. The chief methods for this purpose that have been advocated and relied on in the past are the dis-

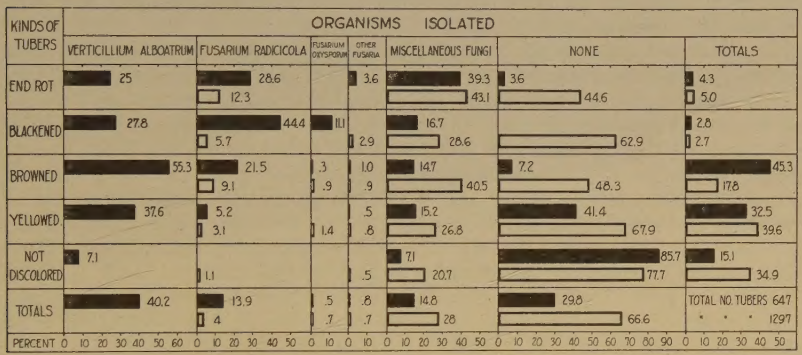


Fig. 7. Stem-end discoloration in potato tubers is unreliable for the determination of the presence of wilt infection. This graph shows the relation between discoloration and the occurrence of various fungi in two lots of potato tubers. The tubers from which these results were obtained were grown from the two longitudinal halves of known wilt-free tubers, one lot, shown in solid black bars, on soil infested by scattering Verticillium-diseased tops the previous fall and the other lot, shown in outlined bars, on adjacent clean, well-rotated soil as a control. Some of the discolored tubers from the diseased soil always showed infection by Verticillium wilt, while none of the discolored tubers from the clean soil showed any infection by this disease.

carding for seed of tubers showing distinct discoloration in the vascular region and the roguing from the seed-plot of the individual plants showing wilt. That these methods are inadequate for successfully controlling the disease and that more care in the roguing of seed-plots must be used are clearly shown by results recently secured and presented here.

Tuber discoloration unreliable for wilt determination. That the presence or absence of discoloration is an unreliable guide to the presence or absence of wilt-producing fungi in potato tubers has been clearly shown on a number of occasions. Pethybridge* in Ireland pointed out that this is far from being an infallible sign. Edson† working in Colorado and Wisconsin

*Pethybridge, G. H. Investigations on potato diseases. (Seventh Report.) Department of Agriculture and Tech. Instr. Ireland Jour. 16:564-596. 1916.

†Edson, H. A. Vascular discoloration of Irish potato tubers. Jour. Agr. Research 20:277-294. 1920.

stated: "In the materials studied, vascular discoloration of the stem-end tissues of Irish potato tubers was not found to be proof of the presence of parasitic fungi. Discolored bundles were often sterile, and fungi were frequently isolated from tissues which appeared normal."

In the work at the Oregon Agricultural Experiment Station extending over several years and dealing with several lots of tubers grown under different conditions, it was found that the presence of discoloration in the stem-end vascular region of potato tubers is not a trustworthy index of the presence of disease-producing organisms therein and ought not to be relied upon exclusively as a guide for the separation of diseased from healthy tubers for planting purposes. For instance, a summary of results from over 12,000 tubers examined in detail in the laboratory showed that only 45 percent of the tubers which were browned in the stem-end vascular region when cultured gave organisms which cause disease in potatoes; 55 percent gave either no organisms or miscellaneous fungi of no apparent importance. Twenty-two percent of the tubers which were distinctly yellowed in the stem-end vascular region and 5 percent of those which showed no discoloration gave organisms parasitic on potatoes, while the others of these lots gave nothing of consequence.

A similar condition for Verticillium is shown (Fig. 7) in a comparison of results from two lots of tubers grown from the two longitudinal halves of 272 tested wilt-free tubers, one lot on soil infested by scattering Verticillium diseased tops the previous fall and the other lot on adjacent clean, well-rotated soil as a control. The discolored tubers grown by the wilt-infested plants on the contaminated soil gave a high percentage of infection with *V. albo-atrum,* whereas the discolored tubers grown by the wilt-free plants on the clean soil showed no infection with this fungus. To make specific comparisons: 45.3 percent of the tubers grown on contaminated soil were definitely colored brown in the vascular region at the stem-end, and of these 55.3 percent gave *V. albo-atrum* and 7.2 percent gave no organism in culture; 17.8 percent of the tubers from the clean soil were stained brown, but none gave *V. albo-atrum* and 48.3 percent gave no organism in culture. A summary of all the discolored tubers from the two plots, listing the "end rot," "blackened," "browned," and "yellowed" tubers together as being discolored, shows that approximately 85 percent of the tubers from the wilt infested plot were discolored and of these 46 percent were invaded by *V. albo-atrum* and approximately 65 percent from the wilt-free plot were discolored, but none of these were invaded by the wilt fungus. The only reasonable conclusions from these data are that the presence or absence of *V. albo-atrum* in potato tubers is determined by the plants that produced them rather than by the presence or absence of tuber stem-end discoloration, and that tuber discoloration cannot be relied on to any considerable extent for the separation of wilt-diseased from healthy tubers.

Results of planting diseased seed in clean soil. That potato wilt is readily transmitted from one season to the next in infected seed potatoes has been demonstrated many times. As an example one season's test showed approximately 30 percent infection of Verticillium in tubers grown from seed potatoes known to be infected by the same fungus when planted (Fig. 1). The tubers produced by one lot of rather badly wilted plants showed 40.2 percent infection with Verticillium when cultured after digging, and another lot gave a crop containing 49 percent infection. The highest percentage of Verticillium infection found in the tubers produced by any considerable

number of plants was 92. This result was secured in the yield of 28 plants of the Up-to-Date variety, which is quite susceptible to this wilt. In a number of instances individual plants of several different varieties have given yields with 100 percent Verticillium infection. The general average, however, as shown by the records, is 30 to 50 percent.

One method that has been frequently recommended for lessening the danger of transmitting the organism in the tubers is the discarding of the stem-end and planting only the eye-end of the tubers for seed purposes. A number of tests conducted indicate that this wilt fungus is not localized at or near the stem-end of affected tubers. In one test where known Verticillium-infected tubers were used for seed the stem-piece plants produced tubers bearing 22.7 percent infection and the eye-piece plants from the same tubers gave a crop with 24.6 percent infection by the same fungus. In another test where seed from wilt-affected plants was used, the stem-piece plants gave 10.8 percent infection and the eye-piece plants 0.5 percent infection of the tubers by Verticillium.

In still another test two lots of Burbank seed potatoes were sorted out of the same bin. A thin slice was cut with a knife from the stem-end of each tuber, exposing the vascular ring to view. One lot of 108 tubers was selected as having distinct discoloration present in this stem-end vascular region and the other lot of 110 tubers as being free of any discoloration; that is, normal in appearance. All the tubers in both lots were cut crosswise into stem and eye halves and planted in rows side by side, the stem pieces in one row and the eye pieces in the adjoining row on soil which had been given a three-year rotation of wheat, clover, and potatoes. The yields of all these plants were dug separately and cultured in the laboratory for the presence of wilt-producing fungi.

The results in mass and in paired hills—that is, from stem- and eye-piece plants from the same seed tuber—showed that the wilt-producing organisms were not encountered any more frequently from the yields of the stem-piece plants than from those of the eye-piece plants. Where discolored seed tubers were used, *Verticillium albo-atrum* was isolated from one or more tubers in the yields of both stem- and eye-end pieces in the case of 8 pairs of plants, from the yield of only the stem-piece plant in 15 pairs, and only eye-piece plant in 28 pairs. The comparable figures for *Fusarium oxysporum* are 18, 41, and 24 respectively. The figures secured from the yields from the non-discolored tubers are 7, 15, and 24 for Verticillium, and 42, 33, and 20 for Fusarium in the three groups, respectively.

The tubers produced by the stem-piece plants from the discolored seed tubers gave a total of 5.3 percent *V. albo-atrum* and 16.1 percent *F. oxysporum;* those from the eye-piece plants from the same seed tubers gave 8.5 percent and 11.7 percent respectively. Those from the stem-piece plants of the non-discolored tubers gave 4.6 and 23 percent and from the eye-piece plants of the same tubers 7.1 and 15.2 percent of the two organisms, respectively. It is worth noting that there was no significant variation in the amount of discoloration present in the yields of these different lots. The discolored-tuber stem-piece plants gave 64.2 percent discoloration in the yield and the eye-piece plants 51.1 percent. The non-discolored tubers gave 54.6 and 57.3 percent in the stem- and eye-piece plants, respectively. Hence there is no correlation here between the presence of seed-tuber stem-end discoloration and the occurrence of wilt-producing fungi in the yields, nor did the stem-piece plants give, in general, any more disease than the eye-piece plants from the same tubers.

From all these figures it is apparent that at best only slight benefit is to be gained in wilt control by the use of only eye-end pieces for seed purposes. Such a practice would have limited application only, being advisable for use in special cases, as for instance, in seed-plots where no special precautions have previously been taken to eliminate wilt from the seed stock. Where the grower is willing to go to the slight extra trouble, there would, however, be no objection to the use of only eye-end pieces in the seed-plot, but one should guard against placing too much reliance on this as an effective wilt control method. In seed stocks that have been grown by careful roguing and other effective practices, it would probably be unnecessary and inadvisable to discard stem-ends and plant only eye-end pieces for potato wilt control.

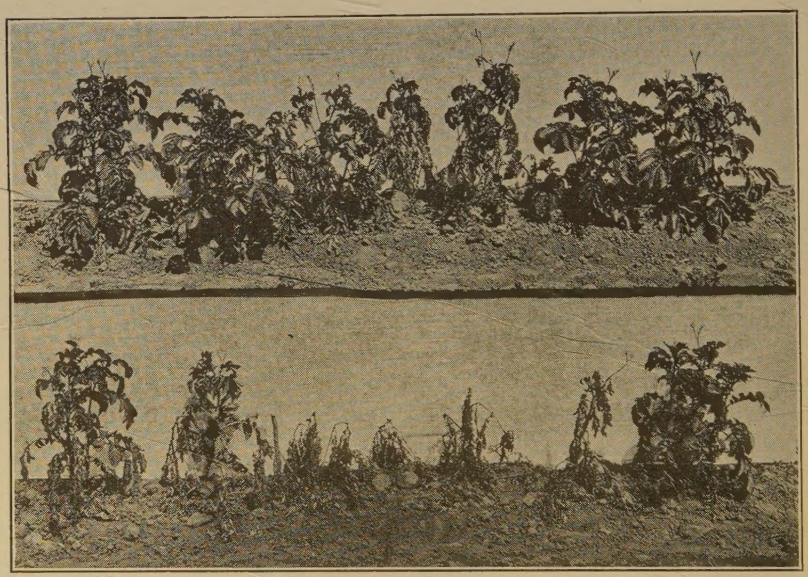


Fig. 8. Verticillium wilt of potatoes spreads from one plant to another in the row during the growing season. The upper illustration shows six plants photographed August 1 of which the two central ones were inoculated at planting time and these only are showing symptoms of wilt. The lower illustration shows the condition of the same six plants on August 31, at which time all the plants were showing wilt except the one at the extreme right. It is interesting to note that even this plant gave one Verticillium-infected tuber out of twelve produced. Thus spread of the disease to the second plant in the row from the one originally diseased is indicated.

Spread of the disease from plant to plant in the row. During the progress of this work it has been noted on a number of occasions that some plants grown on clean soil from tubers free from wilt when planted showed a rather large percentage of infection by *Verticillium albo-atrum* in the yields when dug. For instance in 1917, plants grown on clean soil from known Verticillium-infected seed gave 29.7 percent Verticillium infection in the yields, those grown from tubers invaded by "miscellaneous fungi" gave 13.3 percent Verticillium infection in the yields, and those from tubers apparently free of organisms when planted gave 18.9 percent Verticillium infection. The occurrence of Verticillium in the tubers from these other

plants can be explained from knowledge we now have of the spread of the organism from one plant to another in the row during the growing season. When the data on the yields from these plants were tabulated on the basis of distance of the plants in the row from known Verticillium-infected seed, it was found that in general infection from Verticillium in the yields ran highest in plants located next to a plant grown from a Verticillium-infected seed potato and dropped off to a very low percentage in the tubers from the fifth plants away and beyond, the percentages for plants one to five and beyond being 35.2, 29.4, 31.5, 14.5 and 3, respectively. These figures seem to indicate that Verticillium had spread commonly to the third plant away but not much beyond. It should be added here that the season these potatoes were grown was a favorable one for the development of Verticillium wilt and also that no tests on distance of spread conducted since that time in less favorable years have given results that exceeded or even quite equalled these just reported.

For illustrating spread of the disease from one plant to another in the row, specific reference should be made also to results secured in 1921 in three plots discussed below in more detail under roguing tests. As indicated in the graph (Fig. 9), plants located next in the row to wilted plants but not themselves showing wilt, showed 19 and 24.2 percent wilt infection in the tubers dug in the two plots respectively. And in the second plants away from known wilt-infected plants the average percentage infection of Verticillium in the tubers was 5.4 percent for the three plots. Beyond the second plant away there was only a slight amount of infection in any of the plots. In the case of these plots, then, the disease had spread commonly to the first plant in the row next to the plants visibly affected with wilt and to some extent to the second plant away but not much beyond these (Fig. 8).

Fig. 1 shows two plants which illustrate spread of wilt from one plant to another in the field under natural conditions. The plant at the left was grown from a tuber known to be wilt-infected when planted. It produced 6 tubers weighing 10 ounces, 50 percent of which were infected with Verticillium when dug. The plant at the right was grown from a wilt-free tuber. It remained healthy in appearance nearly up to the end of the growing season and produced a large yield of 22 tubers weighing 7 pounds, 10 ounces, and yet when tested after harvest 45 percent of these tubers showed infection by Verticillium wilt. Infection of this plant without question came from the adjoining diseased plant in the row.

Though spread of the disease from plant to plant within the row appears to be a common occurrence, the disease apparently does not spread readily from one row to another. As an illustration of this non-spread between rows may be mentioned one test in 1917 with two adjoining rows 39 inches apart. In one row the plants were inoculated with Verticillium and gave 99 percent wilt before the end of the season and 49 percent infection in the tubers when dug. The other row was not inoculated and it showed no wilt during the season and gave only 0.8 percent Verticillium-infected tubers when dug.

The exact manner in which spread of the disease between plants is accomplished has not been determined, though all the evidence available leads to the conclusion that it is brought about through the intermingled root systems. That the fungus gains entrance into plants through the roots was indicated by results secured in specific tests conducted for determining the mode of infection of healthy plants in contaminated soil. The fungus was

found first in the roots, then in the stems, and finally in the stolons. Van der Meer* in Holland performed more detailed tests on the mode of infection and concluded that Verticillium can attack and penetrate uninjured roots. It is evident from experiments performed in Oregon that infection of plants may be secured when the fungus is in the soil at considerable distances from the seed piece, definite infection having been secured at distances up to 45 inches from the seed piece. The limit of distance at which infection can occur is apparently determined by the extent of distribution of the root systems in the soil. Probably cultivation which prevents the free intermingling of roots from adjoining rows is the one factor which hinders the spread of the disease from row to row in the field as distance of the rows apart in itself would not be sufficient to preclude this occurrence.

Roguing to avoid wilt infection in seed potatoes. After realizing that Verticillium wilt does spread commonly from plant to plant in the field, it was naturally wondered to what extent this could be avoided by the roguing out of affected plants as they were observed during the growing

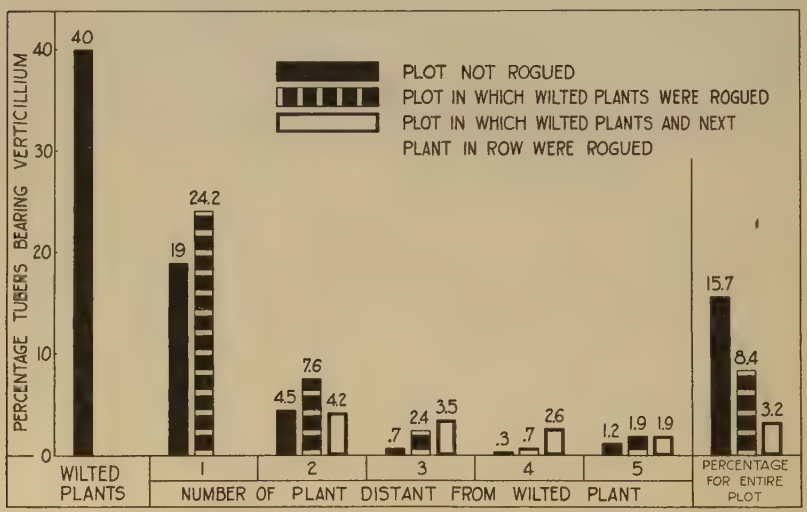


Fig. 9. Graph showing a summary of the results secured from three plots for determining the spread of Verticillium wilt from plant to plant in the row and the influence of the one- and three-plant methods of roguing thereon. The inadequacy for Verticillium wilt control of roguing only visibly wilt-affected plants is shown here in the results from the second plot; for in this case the next plant in the row to a wilted plant, though itself not showing wilt symptoms in the field, gave an average of 24.2 percent Verticillium infection in the yield. In contrast the three-plant method of roguing is quite effective in eliminating this disease from the seed-plot.

season. To get information on this point field tests were conducted for two years. In the 1921 tests three plots were planted side by side with healthy potatoes. In each plot one out of every six seed pieces was inoculated with Verticillium at planting time. These were so placed in the row as to give one original wilt-infested plant and five healthy plants next in the row on

*Van der Meer, J. H. H. Verticillium-wilt of herbaceous and woody plants. Med. Landb. Hoogeschool 28:1-82. 1925.

which observations on the spread of the disease to the healthy uninoculated plants could be made as the season progressed.

In one plot notes were kept on the growth of the plants but no roguing was done. In the second plot all wilted plants were rogued promptly as soon as observed. In the third plot the wilted plants and in addition the next healthy plant on either side of the wilted one in the same row were rogued at the same time. For convenience this is termed the "three-plant method" of roguing. These plots were gone over five times from July 11 to August 22 or as long as wilt could be clearly enough distinguished from maturity to justify additional roguing. After harvest the tubers were tested by culturing in the laboratory for the presence of wilt infection.

In the plot where no roguing was done the plants which showed wilt symptoms during the growing season gave 40 percent infection of Verticillium in the tubers (Fig. 9). The plants located next in the row to a wilted plant but not themselves showing wilt gave 19 percent Verticillium infection in the yields; those which were two plants away gave 4.5 percent, and those three plants away gave 0.7 percent Verticillium infection in the yields. These records are in general harmony with those of former years and indicate extensive contamination of tubers in hills healthy in appearance but adjoining visibly wilt-affected plants. They also reveal noticeable spread of the organism to the tubers of the second plant in the row from a wilted plant.

In the second plot, where all plants showing wilt were rogued as soon as noted, the adjoining plants in the row gave 24.2 percent infection in the yields. The second plants away gave 7.6 percent, and the third plants gave 2.4 percent infection from Verticillium.

In the third plot, where the wilted plants and the next healthy plant on either side in the same row were rogued at the same time—that is, where the three-plant method of roguing was used—the second plant away from the plant which showed wilt gave 4.2 percent and the third plant gave 3.5 percent infection of Verticillium in the yields. The variations in the amount of wilt infection present in the three plots in the tubers of the third, fourth, and fifth plants distant from the wilted plants are taken as being due chiefly to experimental error and are not considered as having any special significance.

The figures secured indicate a very decided advantage of the three-plant method of roguing over the ordinary roguing of only the plants which can be detected on appearance to be wilt-infected. This is evident from the high infection of the tubers in the plants adjoining visibly wilted plants and is also well shown by the percentages of Verticillium in the tubers remaining in the plots following the two methods of roguing. For instance, in the second plot, where only visibly wilt-affected plants were rogued, 24.2 percent of the tubers from the next adjoining hill were infected and a total of 8.4 percent Verticillium infection was secured in the tubers harvested from the entire plot; whereas in the third plot, where the wilted and adjoining plants were rogued only 3.2 percent Verticillium infection remained in the tubers harvested from the entire plot. In this latter case, following the three-plant method of roguing, this represents a reduction of from slightly more than 22 percent visible wilt infection in the plants to 3.2 percent infection in the tubers in one season's time.

Fig. 8 shows six plants from the non-rogued plot photographed August 1, when only the two central inoculated hills had wilt, and again on August

31, when the two adjoining plants on one side and one adjoining plant on the other side of the inoculated hills were plainly wilt diseased. It is worthy of note here that the one plant in this illustration which did not show wilt in the field gave one Verticillium-infected tuber out of the 12 produced.

From the above data it is clearly apparent that not all plants that produce Verticillium-infected yields show visible symptoms of wilt infection in the field. A great many plants have been grown at different times that exhibited no detectable wilt in the field but which produced tubers containing a high percentage of Verticillium infection. This is doubtless to be explained on the basis that the effects of the disease on the plant itself were so slight as frequently to escape detection because infection resulting from spread in the row took place late in the season. Such late infection causes little or no change in the appearance of the plant and cannot be clearly distinguished from normal maturity of the vines. It is not known how late infection may gain entrance into plants and grow on into the tubers; it is believed, however, that this may take place quite late in the season, possibly nearly up to harvest time. To make a common practice of the three-plant method of roguing would eliminate the great majority of this type of infection and undoubtedly result in a short time in the reduction of damage from Verticillium to a negligible quantity.

In many fields in Western Oregon there is frequently considerable variation in the final maturing of the different plants in the same field that is not associated in any way with the occurrence of the wilt disease. This, however, ordinarily need not cause confusion in roguing since only the visibly wilt-affected and the adjoining plants in the same row should be rogued out. Where Verticillium wilt is present in the field it commonly makes itself sufficiently evident, particularly in the original diseased plants, far enough in advance of maturity to permit of close but not excessive roguing.

It is not known at the present time that there is any particular advantage to be gained by the use of the three-plant method of roguing for any of the wilts of potatoes besides that caused by Verticillium. Since Verticillium wilt is the common wilt encountered, however, and the one which causes the greater amount of damage, no one should hesitate when wilt is present to apply this method of roguing to all potatoes grown in the seed-plot and in all fields of potatoes grown for seed purposes.

Maintenance of a seed-plot for wilt control. Apparently there is no method that can be used so effectively in cleaning up wilt-infected stocks in so short a time as the practice of the three-plant method of roguing. This method has its most practical use in connection with a seed-plot. As discussed here a potato seed-plot is any part of the potato crop that is given special treatment for the securing of better seed for the next year's crop on the same farm. Wilt control can be accomplished with the minimum of trouble and labor by the use of the seed-plot. In a seed-plot one can afford to take the time and pains for performing the essential tasks necessary for controlling this seed-borne disease here, while it would be much more difficult and less practical to accomplish the same thing if applied to the whole field. If proper care is used in growing the potatoes in the seed-plot, it will not be necessary to do much if any roguing in the main field the following year. For this reason the importance of the seed-plot in the maintenance of a source of relatively wilt-free seed potatoes on each farm wherever practicable cannot be overestimated.

To offer concrete suggestions for the maintenance of a seed-plot for the control of not only wilt but also other important diseases as well, a farm plan has been made showing the location of the potato seed-plot separate from the main field and its relation to the other crops in each year of one four-year crop-rotation period (Fig. 10). These plans, made in cooperation with the department of Farm Management, show what is regarded as the best basic crop rotation for Western Oregon, consisting of grain, clover seed, clover hay, and a cultivated crop. A variety of materials including potatoes, corn, kale, etc., may be used for the cultivated crop. Much of the farming

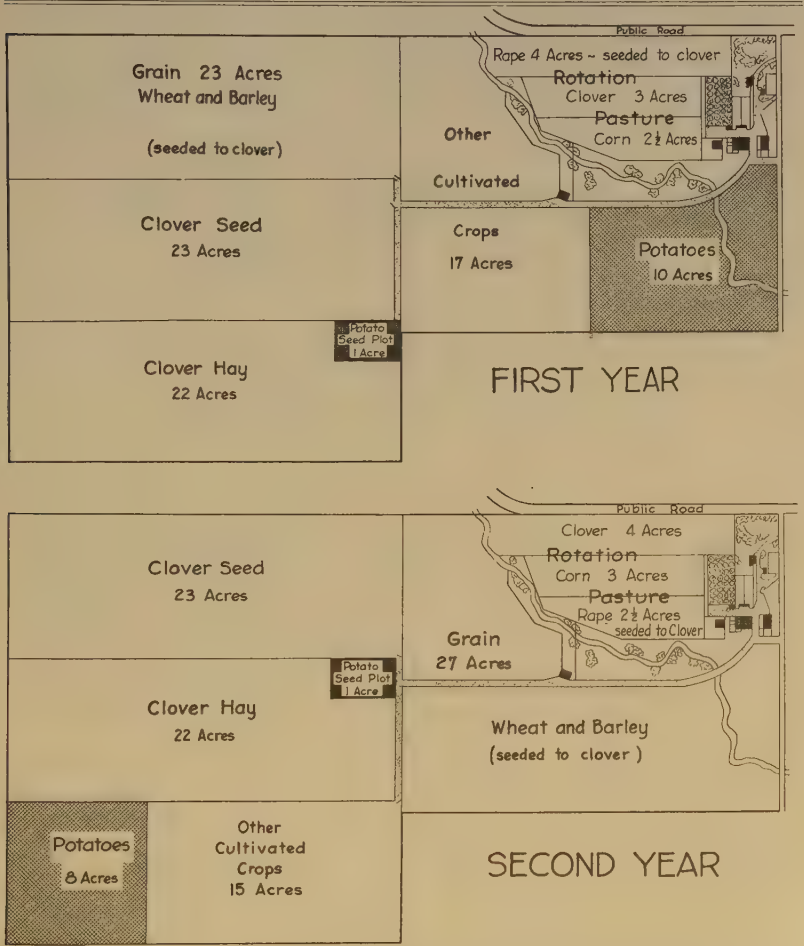
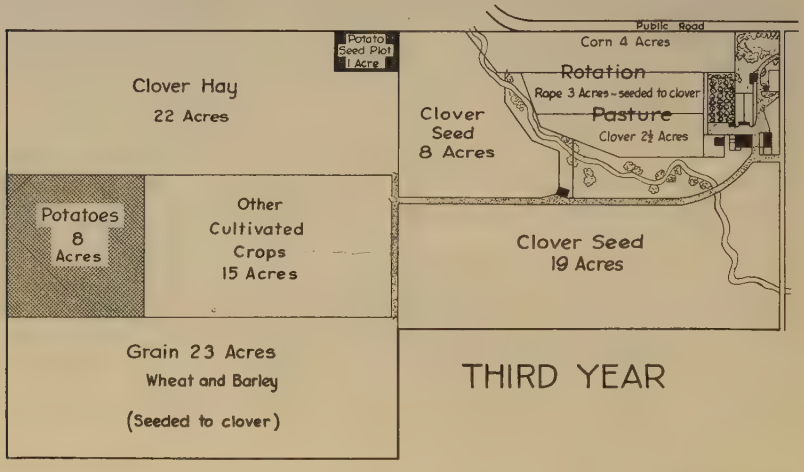
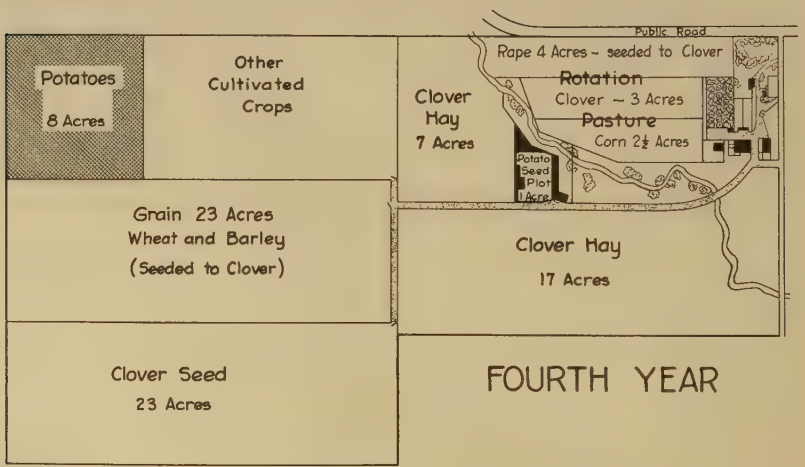


Fig. 10. Plan of a Western Oregon farm showing suggested locations for the potato seed-plot and the main potato field each year in a four-year rotation period for potato disease control. In these plans the seed-plot is separated from the main field of potatoes by at least 300 feet in order to guard against spread from one potato field to another of the mosaic and other virus diseases which are commonly insect carried. These plans, made in cooperation with the department of Farm Management, make use of what is

of Western Oregon could, with great advantage, be carried on after this plan or a modification of it to suit individual needs. For other sections of the state a comparable plan can be worked out that is suited to local conditions in the particular area.

Inasmuch as a seed-plot is maintained for controlling other diseases besides wilt it seems advisable here to mention briefly the importance and necessity of isolating the seed-plot particularly for virus disease control. In these plans the seed-plot is separated from the main field of potatoes in order to guard against spread from one potato field to another of the mosaic and other virus diseases which are commonly carried by insects, particularly





regarded as the best basic crop rotation for Western Oregon, consisting of grain, clover seed, clover hay, and a cultivated crop. Potatoes would generally occupy only a part of the space devoted to cultivated crops. Much of the farming of Western Oregon could, with great advantage, be carried on after this plan or a modification of it to suit individual needs.

aphids. When aphids feed on a diseased plant then on healthy plants the virus diseases are transmitted to the healthy plants. Any diseased plants located near the seed-plot and left without roguing thus serve as a source of contamination to the healthy plants in the seed-plot. If healthy plants are infected by the virus disease late in the season they may show no symptoms of disease that year, though all the tubers would give rise to diseased plants if used for seed the following year. Consequently, plants in the seed-plot that are infected late cannot be rogued because the disease cannot be detected that season. To avoid the chance of appreciable insect migration and consequent disease transmission from adjoining potatoes which are not rogued as carefully or as thoroughly as those in the seed-plot, a certain degree of separation between the seed-plot and any other potatoes is quite necessary. Isolation of the seed-plot by a distance of at least 300 feet from other potatoes is now regarded as adequate and essential to success in controlling these virus diseases.

It is sufficient to have the seed-plot about one-tenth the size of the main field as this will be large enough to produce all the seed potatoes that will be required for planting both the seed-plot and the main field the following year. In these plans the seed-plot is always maintained in the major rotation as it is inadvisable to disturb the minor pasture rotation for this purpose.

As soon as the plants are large enough to show disease, weaknesses, or varietal mixtures, the seed-plot should be rogued thoroughly and all such plants removed. In the case of wilt the three-plant method of roguing should by all means be used. The plot should be gone over several times during the season to remove the undesirable plants as they develop. In this way only the more desirable plants will be left to mature and furnish tubers for seed. Out of these remaining plants in the seed-plot enough of the high-yielding and most uniform, typical hills, preferably from places in the field where there is a full stand, should be selected at harvest time to be used for planting the seed-plot the following year; the remainder can be planted in the general field. This simple but effective plan furnishes a method of continuous improvement of the seed potatoes which in a few years, if combined with proper crop rotation and seed disinfection, will reduce most of the tuber-borne diseases to a negligible quantity and will greatly increase the average yield of potatoes.

WILT DISEASES ARE HELD OVER IN THE SOIL

The utilization of crop rotations to avoid infection of potato plants with wilt from the soil has been commonly appreciated and long used. The use on all farms of well planned rotation systems for this purpose, however, is not as commonly practiced as conditions justify. Consequently, it is the purpose to give here some results showing the necessity for the use of crop rotations for wilt control and to give available evidence on the length of rotation sufficient for avoiding infection from the soil. The results secured with Verticillium here indicated that with this fungus a three-year rotation is sufficient for avoiding infection from the soil. A longer rotation than this would be necessary only if potatoes were held over excessively in the soil as volunteers, to afford a greater margin of safety, or out of consideration to other diseases to which the potato is subject. Since Fusarium, however, is not as readily eliminated from the soil by rotation as Verticillium and because other diseases such as Rhizoctonia persist in the soil rather

commonly for three years, nothing short of a four-year rotation is ordinarily advisable, particularly for the production of good seed potatoes (see cover page). This does not mean that good crops cannot be grown with a shorter rotation, but it does mean that with a rotation of this length risks from damage from soil-borne diseases are very materially reduced. The growers of the state could with great advantage make more general use of well planned crop rotations of sufficient length to lessen the danger of contamination of their potato crops from the soil.

Fig. 11. Two plants, same age, from the longitudinal halves of the same tuber; upper one grown on soil infested with Verticillium wilt from the previous crop, lower one on soil which had not grown potatoes for five years. Infection of potato plants by wilt from the soil can be avoided only by proper rotation of the crops.

Results of planting clean seed on contaminated soil. As illustrating the need for rotation in avoiding infection from the soil, mention will be made only of one experiment, in which use was made of old diseased potato tops as the source of the organism in the soil. In the fall potato vines from Verticillium wilt diseased hills were collected from various sources and scattered over a plot of ground suitable for the test. The ground selected had not grown potatoes recently and had been well rotated. The old diseased

potato tops were scattered at the rate of about one stalk for every four square feet. In the early winter this ground was double disked and in the spring was plowed and prepared for planting. The seed potatoes selected for planting were wilt-free and were cut into halves longitudinally for planting, one set on the contaminated soil and the other set of halves on similar except uncontaminated soil a few yards away as control.

During growth 90 percent of the plants on the diseased soil showed wilt, while none of the plants on the control soil were listed as wilted (Fig. 11). When harvested and tested by culturing in the laboratory, 40.2 percent of the tubers produced on the former plot were infected by the Verticillium wilt fungus, and none of those from the latter were so affected. The weight of the crop harvested from the diseased plot was only 32.5 percent of that from the control plot. Not all of this reduction in yields is, however, to be attributed to Verticillium wilt alone as no doubt other factors entered in. It is, of course, to be expected that where diseased potato tops were used to contaminate the soil a multitude of organisms besides the one under test would be introduced to affect the crop and complicate the results. From this experiment it is evident that infection takes place very readily from the soil and that old diseased tops from previous crops may be a very important source of infection unless precautions are used to avoid this by crop rotations.

As mentioned above, Verticillium wilt gains entrance to potato plants from the soil through invasion of the roots. In Colorado, however, where the prevailing wilt of potatoes is caused by Fusarium, infection of the plants by this fungus from the soil appears to occur most commonly through the seed piece, first rotting the seed piece then advancing into the stalks.* In tests conducted there plants grown from cut seed pieces were often very generally infected, while those grown from whole seed pieces were only rarely affected. From this fact it would appear that in those areas of Oregon where Fusarium wilt is relatively prevalent some benefit might be secured from the use of whole rather than cut seed pieces in order to avoid infection by Fusarium from contaminated soil. On the other hand it must be mentioned here that infection of a plant by Verticillium wilt through the seed piece from the soil has never been observed and probably seldom if ever occurs. Consequently, the use of whole seed for Verticillium wilt control would apparently be of no value.

Length of rotation necessary to avoid wilt infection from the soil. To secure some knowledge of how long the Verticillium wilt fungus will stay alive in the soil, and still cause disease in healthy potatoes planted therein, some field planting trials on controlled experimental plots have been made. Since no diseased field available was suitable for the tests, a selected piece of ground containing 1½ acres was laid out into sixteen 1/20 acre plots. It was thought that a four-year rotation would be sufficient for freeing the soil of infection, and provision was therefore made for determining the influence of one-, two-, three-, and four-year rotations for this purpose.

The tests were run in duplicate to avoid variations in amount of disease due to differences in climatic conditions from year to year. The test plots were contaminated by growing a crop of diseased potatoes thereon. For each test plot there was a corresponding control or clean soil plot on which

*MacMillan, H. G. Fusarium-blight of potatoes under irrigation. Jour. Agri. Research 16:279-304. 1919.

the crops were grown in the same order and at the same time as on the test plot, the only difference between the plots being the introduction of the disease in the beginning in the one case and not in the other. For growing the test crop to determine the amount of infection from the soil, use was made of the most nearly wilt-free seed potatoes of the Up-to-Date variety available. The percentage of tubers bearing infection by Verticillium wilt in the different plots, as determined by laboratory tests after digging, is used as the index for judging the extent of infection from the soil.

The crops used in the rotations were as follows: one-year rotation, potatoes following potatoes; two-year rotation, grain and potatoes; three-year rotation, grain, clover, and potatoes; and four-year rotation, grain, clover, clover, and potatoes.

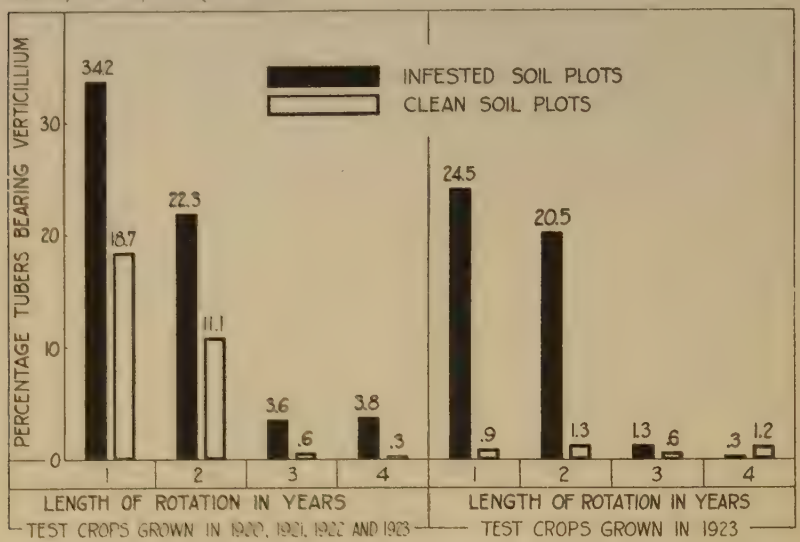


Fig. 12. Graph showing results secured from plots conducted for determining the length of rotation necessary for avoiding Verticillium wilt infection from the soil. The three- and four-year rotations can be considered to have given effective disease control.

As shown by the summarized results (Fig 12), in both sets of tests the one- and two-year rotation plots gave a considerable amount of the wilt disease due to infection from the soil, and the three- and four-year rotations can be considered to have given practically complete control. It is true that the three- and four-year rotation plots in the first set of tests do show a noticeable amount of wilt—3.6 and 3.8 percent, respectively. It is believed that this infection resulted from some uncontrolled factors in carrying out the tests rather than the holding over of the fungus in the soil for this length of time.

Unfortunately, in conducting the tests there were at least four opportunities for introducing contamination into the soil of the control plots—either from transfer of material from plot to plot or by the use of seed potatoes not entirely free from disease that may have entered into and complicated the results. In the first place, the plots were under flood water twice; second, the plots were by error disked crosswise once under conditions favorable to

transfer of contamination; third, the seed potatoes used for growing the test crops were not always wilt-free when planted and carried some infection into the plots; and fourth, the seed potatoes used on the first set of control plots the first year contained some wilt when planted, which gave rise to diseased plants. This material held the fungus alive in the soil over winter and undoubtedly was the cause of the appreciable infection of 18.7 and 11.1 percent in the one- and two-year rotation control plots, respectively. Since all four of the control plots in this series, however, were originally planted with the same seed, and since the test crops grown on the three- and four-year rotation plots showed so little disease, 0.6 and 0.3 percent respectively, as compared to the plots receiving one- and two-year rotations, this series of plots really furnishes an additional illustration of the practically complete effectiveness of the three- and four-year rotations in eliminating Verticillium wilt infection from the soil. The longer rotation of four years is preferable for potatoes because it increases the margin of safety for Verticillium wilt control and because the three-year rotation is not effective in controlling some other diseases which affect potatoes.

Unfortunately the potato wilt due to Fusarium does not lend itself so readily to control by crop rotation as does that due to Verticillium. It appears to be rather generally true that this fungus is frequently present in soils which have received long and for most purposes adequate rotation with other crops. And, moreover, it has been isolated from soils which have never been planted to potatoes. Since this fungus, however, is not as actively parasitic on potatoes and does not cause as much damage when present as Verticillium, and since the practice of the four-year rotation tends to reduce the abundance of this fungus in the soil, this source of trouble is generally not of such great importance. It needs to be borne in mind that this disease is not entirely controlled by crop rotation.

SUSCEPTIBILITY OF POTATO VARIETIES TO WILT

No attempt has been made to conduct comprehensive tests of the comparative susceptibility of different varieties of potatotes to the wilt disease. During the progress of the investigation of Verticillium wilt, some information has been collected to which brief reference will be made. This disease has been encountered on twelve varieties, including our most popular market varieties, as follows: American Wonder, Burbank, Earliest of All, Early Rose, Garnet Chili, Gold Coin, Irish Cobbler, Netted Gem, Pride of Multnomah, Rural New Yorker, Up-to-Date, and Uncle Sam. Comparative tests with some of these and observations on the others have indicated no significant difference in susceptibility to the disease. Some varieties give a lower percentage of infected tubers in wilted hills than others, but this appears to be due to earliness of maturity rather than to resistance to the disease. It is sufficient to say that at the present time no use can be made of this factor in the control of the disease.

DISTRIBUTION AND IMPORTANCE OF POTATO WILT IN OREGON

Although there has been no opportunity to make a systematic survey of the distribution of potato wilt in the entire state, this disease has been encountered at one time or another in more than half of the counties of the state, including all of the more important potato producing areas. It probably occurs in the other counties as well. It is only rarely that it is found affecting as high as 30 percent of the plants in any field. The more usual amounts found are from 5 to 7 percent. In the work on certification of potatoes in 1918, Verticillium wilt was the second factor in the order of importance in causing fields entered to fail to pass inspections. Since then the situation in regard to this disease has shown improvement. The wilt caused by Verticillium is more commonly encountered and causes a greater reduction in the yield than that due to Fusarium. If the disease attacks the plants early in their growth the yield is usually greatly reduced, but if the attack comes late in the season the crop is practically normal in amount, though often a high percentage of the tubers carry the disease. Frequently the yield of an affected plant is reduced to about 30 percent of that of a normal plant, though the average is probably about 50 percent.

Wilt does not cause as much loss as two other potato diseases. From all available information it appears at the present time that Rhizoctonia annually causes a greater reduction in the yield of potatoes than does any other one disease. Mosaic diseases including the rugose and mild types are perhaps second in seriousness and wilt third. Rhizoctonia is rather successfully controlled by crop rotation and seed treatment both of which methods are comparatively easily applied. The mosaic diseases can be controlled only by the most rigid roguing in the seed-plot, and at best this will probably not be entirely effective. Wilt is controlled by crop rotation and rigid roguing in the seed-plot. Of all the diseases affecting potatoes here, wilt is probably second in importance only to the mosaic diseases from the standpoint of difficulty of control. It behooves all potato growers and particularly those producing seed potatoes to make more effective use of the control measures now available for reducing the damage from the wilt disease.

SUMMARY

Wilt is an important disease of potatoes in Oregon, and is held in check only by the use of considerable care in the application of control measures.

Wilt is caused by the growth of parasitic fungi in the tissues of the roots and stems commonly resulting in premature death of the plants. *Verticillium albo-atrum* and *Fusarium oxysporum* are the fungi generally responsible for this disease, of which the former is much more important here.

Wilt is typically characterized by the slow yellowing and drooping of the lower older leaves, followed by the gradual yellowing, browning, and wilting usually of the entire plant. The vascular or woody tissues of the stems invariably show discolored yellow to brown streaks often extending from the base well into the top. The tubers in wilt-affected hills generally though less regularly show discolored strands or a ring varying from light yellow to brown or black extending for varying distances into the tuber from the point of stolon attachment and confined to the vascular region.

The wilt producing organisms are carried extensively in tubers from diseased hills and where used for seed the next year readily give rise to disease particularly in the case of those infected by Verticillium.

The presence of discoloration in the stem-end vascular region of potato tubers is not a trustworthy index of the presence of disease-producing organisms therein and ought not to be relied upon exclusively as a guide for the separation of diseased from healthy tubers for planting purposes.

The stem-end seed pieces did not seem to give more disease either in the plants or in the tubers produced therefrom than the eye-end seed pieces of the same infected tubers. The differences are at least so slight that it apparently is not advisable in attempting to avoid wilt in seed potatoes to rely much on the practice of discarding the stem-ends and planting only the eye-ends of tubers suspected of containing wilt organisms.

The use of whole seed potatoes for avoiding infection by Fusarium from the soil may be of some value in those areas where this disease is a serious factor because infection of the plants by this fungus often occurs through the cut seed piece. On the other hand, the use of whole seed would have no value for avoiding Verticillium wilt coming from the soil because this fungus enters the plants from the soil through the roots and apparently never enters through the seed piece.

Verticillium wilt spreads from one plant to another in the row during the growing season. Infection of the second plant away from the originally wilted plant in the same row is not uncommon, and noticeable spread to the third plant distant has been observed. This spread of the fungus from one plant to another apparently takes place underground through contact of the root system.

Many potato plants contaminated from the adjoining wilt-diseased plants do not show visible wilt symptoms in the field probably because of late infection. Consequently all wilt-infected plants cannot be detected by field inspections. For this reason effective control of the disease cannot be secured by the roguing of only the visibly wilted plants. For effective control of Verticillium wilt use must be made of the three-plant method of roguing; that is, the noticeably wilt-diseased plant and the next-adjoining healthy appearing plant on either side in the same row should be removed at the same time.

Roguing for wilt control can be most effectively used in the seed-plot maintained for producing good seed for use in the general field. In every locality where home-grown seed can be maintained in good productive condition from year to year, the use of a seed-plot should become a part of the general practice of every farm.

Potato wilt lives over the winter in old tops in the soil and very readily causes disease in wilt-free potatoes planted therein. Field rotation trials showed that a two-year rotation was ineffective for avoiding Verticillium infection from the soil. On the other hand, three- and four-year rotations apparently can be considered completely effective in eliminating this fungus from the soil. The best basic crop rotation for use in Western Oregon is grain, clover seed, clover hay, and a cultivated crop. The more general use of this rotation or a modification of it to suit individual needs would do much to lessen the damage from potato diseases.

Of the twelve potato varieties noted particularly, none seems to possess any appreciable resistance to Verticillium wilt.

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